GEOLOGICAL INVESTIGATION OF THE CLAYS OF RIVERSIDE AND ORANGE COUNTIES, SOUTHERN CALIFORNIA *

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ABSTRACT

One of the three major clay-producing districts of California lies in Riverside and Orange Counties. The more commercially important clay pits and mines are distributed in the form of a horseshoe, whose axis, trending northwest-southeast, roughly coincides with the crest of

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the Santa Ana Range. The eastern limb lies in the Elsinore-Temescal Valley. The apex or closed end corresponds with the northern tip of the range, while the western end lies in the foothills of the Santa Ana Mountains.

According to ceramic use, these clays comprise many types but all can be classified into three broad divisions, namely, fire-clays, refractory bond-clays, and red-burning clays. Although more than thirty different clays are mined within this area, no one clay is used alone, all clay wares produced being a mixture of two or more separate types.

According to origin, both residual and transported clays are present. All of the transported and a portion of the residual types apparently belong, geologically, to one Tertiary formation, known as the Martinez, of Eocene, age. The clays are thus a part of a sedimentary series, considered to have been deposited under estuarine conditions at the edge of a gradually encroaching sea. Coal is found in

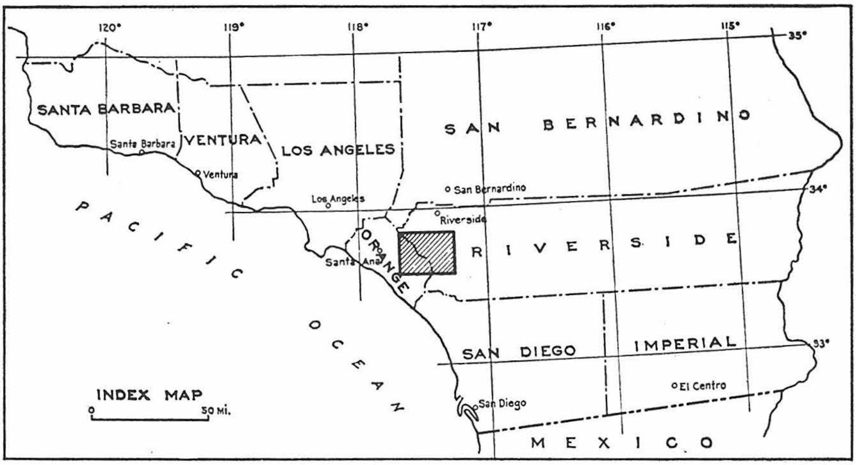

FIG. 1. Index map of the area described in this report on clay deposits of Orange and Riverside counties.

close association with all of the transported clays. Its presence indicates that a humid-temperate climate existed when these clays were deposited. Although the presence of organic acids undoubtedly played a part in the formation of some of the clays derived from the original materials, certain other types of the residual class can not be explained in this manner, since they are not associated with coal. Volcanic material of a rhyolitic type has been found to be present both *in situ* and in the sediments and to have been altered in place, thus giving rise to the formation of residual and transported clays, which are bentonitic when derived from tuffaceous material.

INTRODUCTION

Location of the Deposits.

The most important clay-producing areas in southern California are confined to three counties, namely, in rapidly decreasing order of importance, Riverside, Orange, and San Diego. Only a few of the more important occurrences in Riverside and Orange counties are described in this paper. For further discussion of individual deposits the reader is referred to the excellent state report by Dietrich.[1]

The Elsinore and Corona topographic quadrangles of the U. S. Geological Survey cover the area under discussion. The general localities of the clay-producing properties may be found on Plate 1.

Extent of Work.

Although the deposits have been described by Dietrich, Ries,[2] Linton,[3] Hill,[4] Burchfield,[5] and others, very little geologic work has heretofore been published on the clays of southern California, considering this area as a unit.

This report embodies information gathered in the field in 1929, 1930 and 1931. It describes the general geologic structure of the area, the stratigraphy which has a bearing on the origin and conditions of deposition of the clays, and the details of the more important types of deposits. While some of the problems of the origin of the clays are herein considered, it is intended that a more extended discussion will be published later, following the completion of a projected program of research.

Acknowledgments.

General supervision of the early part of the work was helpfully contributed by the staff and graduate student members of the Balch Graduate School of the Geological Sciences of the California Institute of Technology, Pasadena, California. Doctors J. P. Buwalda, Rene Engel, F. L. Ransome, W. P. Woodring and B. N. Moore are deserving of particular mention.

A considerable proportion of the data published herein was collected during the time the author held the position of consulting geologist for the Pacific Clay Products Company of Los Angeles, Calif. This discussion is, in reality, a continuation of a program of research initiated by Mr. Robert Linton of the Pacific Clay Products, and acknowledgments are due to him and his company for permission to publish this manuscript. William McClintock, Charles McClintock and Gus McClintock of that organization also contributed many suggestions and extended various courtesies.

Acknowledgments are also due to Dr. A. O. Woodford, Mr. William Hill and Mr. P. H. Dudley of Pomona College for their interest and cooperation.

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[1] Dietrich, W. F., Clay resources and the ceramic industry of California: Calif. State Div. of Mines and Mining, Bull. 99, 1928.

[2] Ries, H., Clays, their occurrence, properties and uses: 3d Edition, John Wiley & Sons. 1927.

[3] Linton, R., Tertiary Clays of Southern Calif.: Jour. Am. Ceram. Soc., vol. 11, No. 10, 1928.

[4] Hill, J. H., Clay deposits of the Alberhill Coal and Clay Co.: Calif. State Mineralogist, Report XIX, 1923, p. 185-210.

[5] Burchfield, B. M., Refractory clays of the Alberhill, California deposits: Jour. Am. Chem. Soc., vol. 6, 1924, p. 1167.

CLASSIFICATION OF THE CLAYS

COMMERCIAL CLASSIFICATION

Generally speaking, the clays found in the areas described in this report comprise three main commercial groups: (1) fire-clays, (2) refractory bond clays, and (3) low-vitrification point red-burning clays.

Fire Clays.

The term fire-clay, properly speaking, refers to those clays capable of withstanding a high degree of heat. They are divided into three classes: plastic, nonplastic and flint fire-clays. They may or may not possess a high degree of plasticity. Those fire-clays which possess good plasticity, and good bonding powers when wet, dried or fired are generally placed by ceramists in a separate division, i.e., refractory bond clays. The fire-clays of this district have a fusing point above cone 27 (1605° C.) and a fairly small shrinkage.

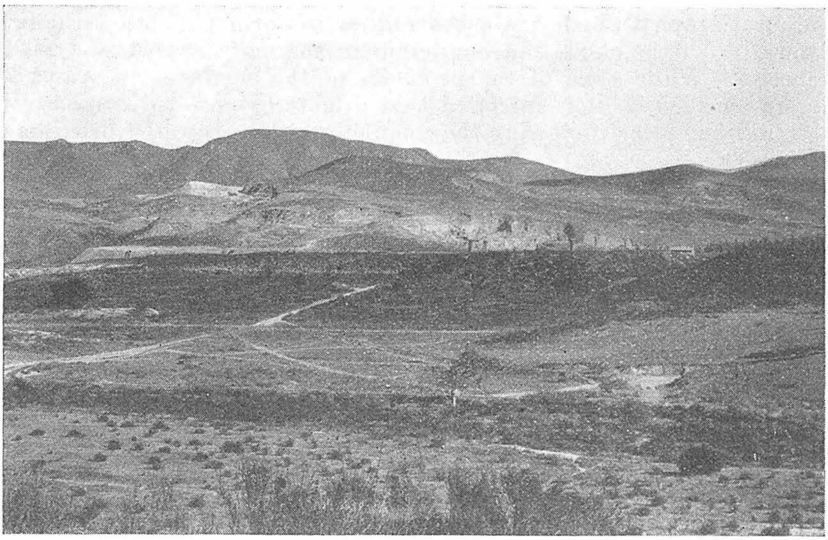

FIG. 2. Alberhill district looking east across the valley. The Alberhill mines are located in the hill in the middle distance. The large pit in the center is the Main pit, the one at the north side (left) is the Douglass pit. In the right foreground is the Pink Mottle pit of the Los Angeles Brick Company.

Plastic Fire-Clay. The plastic fire-clay group overlaps the refractory bond clays, and different manufacturers use the same clay for the two purposes. In general, plastic fire-clays possess a smaller shrinkage and a smaller fired strength than the bond clays, and usually are simply bond clays contaminated by a larger amount of sand. Plastic fire-clays contain a low percentage of fluxing impurities such as iron oxide, lime, magnesia and alkalies, and are invariably white or gray in color.

Non-plastic Fire-Clay, 'Bone' and *Nodular Fire-Clay.* The nonplastic fire-clays include for the most part those clays known as 'bone' to the ceramist of the western States. The distinguishing characteristic of bone, aside from nonplasticity, is its pisolitic structure, which may vary from a few irregularly spaced angular grains included in the clay, to a solid mass of rounded pisolites. The presence of these globular concretions have been taken in common geological usage to indicate the presence of gibbsite, or diaspore. Petrographic examination of thin sections of this material, however, failed to yield any substantiation of this supposition, although it was noted that the presence of the rounded pisolites invariably indicated a high alumina content which may be due to the presence of bauxite or amorphous alumina hydrate.

Flint Fire-Clay. The flint fire-clays develop but little plasticity even when aged. They are hard and flint-like, with a smooth conchoidal fracture, and possess a very dense texture. It is not known in what specific characters the flint fire-clays differ from the ordinary plastic fire-clays. In this district, however, the original materials of the flint fire-clays are believed to have gone farther along in the process of decomposition and elimination of impurities. Further, the flint fire-clays are only found in areas in which the sediments have suffered a comparatively greater amount of diastrophism. The physical characters of the clays of this type may be due to recrystallization of the mineral components of the clay in this horizon.

Uses of Fire-Clays. There is almost an endless variety of refractory clays. In general, they are employed in mixtures used in the manufacture of various shapes of fire-brick, locomotive and furnace linings, saggers, etc. Some of these wares must resist heat alone, others rapid changes in temperature, abrasion, or chemical corrosion; many are called upon to resist compressional forces while at a high temperature. Consequently, the aim of the manufacturer is to select a mixture of clays which will give a ware best adapted to resist the environment under which it is to be used.

Refractory Bond Clays.

The refractory bond clays include those clays which, in addition to their refractory character, have a strong bonding power. The small amount of ball-clays found in this district are included under this class. In general, clays in this class should have a high transverse strength and should be able to bind together materials of less cohesiveness. In the area concerned the plastic fire-clays are in reality bond clays which, by reason of the sand included in the material, can not to any great extent be further admixed with low strength materials. Therefore the qualities described under plastic fire-clays also apply to this class. In addition to their use in refractory shapes, the refractory bond clays are also widely employed as a plasticizing agent in white-ware mixtures.

Red-Burning Clays.

The low-vitrification-point red-burning clays include those materials which contain sufficient iron oxide and other fluxes so that they have the properties their name implies. They usually represent material which was originally more impure or insufficiently decomposed and leached, either in place, previous to transportation, or during transportation. In a few cases, the presence of fluxes is due to contamination by solutions bringing impurities from the outside, and depositing them in the pore spaces of the materials.

The specifications of this type of clay are as follows: good plasticity, ability to dry and burn without warping or cracking, well-dried or burned transverse strength, freedom from lumpy impurities and soluble salts, and ability to take a salt-glaze.

The uses of this type of clays are innumerable. Any product in which a red color or low vitrification temperature are desired, may usually be made of this material. Sewer pipe, common brick, hollow and roofing tile, electric conduit, and red pottery are examples.

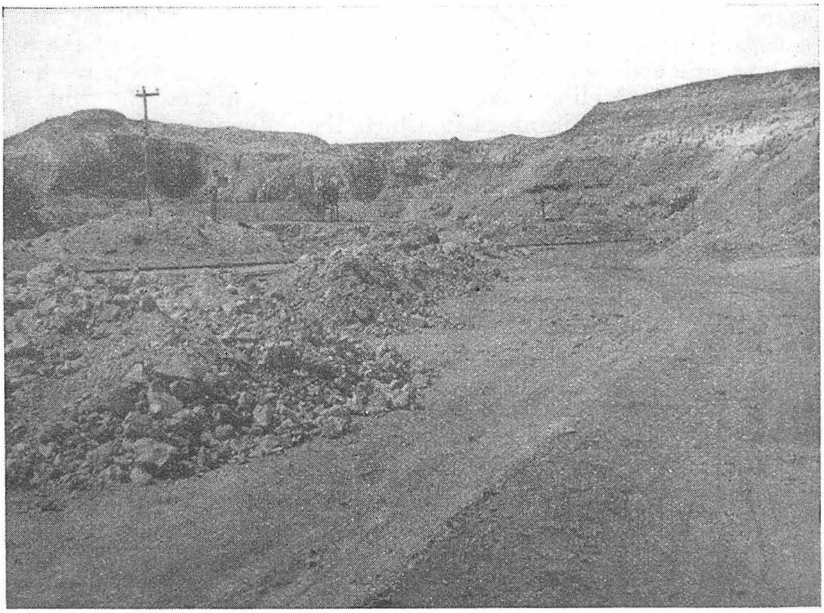

FIG. 3. Main pit at Alberhill. This is the largest clay mine in California. The beds of transported clays exposed, that have been mined, comprise a total thickness of over 50 ft. (right) and are cut off by a north-south fault (left center).

GENETIC CLASSIFICATION

According to origin, the clays found in the district may be divided into two main classes: (1) residual clays and (2) transported clays. Residual clays include those which have developed by alteration in place of the source material, while transported clays are those which have been produced by alteration before or during transportation. Minor secondary changes have taken place in the clays of both classes.

Most of the clays in the district, including all of the purer types, belong to the transported class. Thus fire-clays and refractory bond clays represent the transported class, while the red-burning clays may belong to either the transported or the residual class. Examples of the transported class include all of the Corona-McKnight, Goat Ranch-Claymont, Serrano El Toro, and most of the Alberhill types of clay. Residual clays are represented by the Wildomar, and portions of the Alberhill group.

Some of the clays dealt with in this discussion might be termed bentonitic in the sense of their origin. That is, they are considered to be the result of chemical alteration and devitrification of the glassy particles of tuffs. The term, however, as used here does not necessarily connote the physical properties of swelling, etc., which the nontechnical use of the word implies.

GENERAL GEOLOGY

STRATIGRAPHY

Basement Complex.

Practically all of the ranges in southern California contain a great variety of metamorphic and igneous rocks. According to Engel,[6] the east and west sides of the Elsinore and Temescal valleys are made up of metamorphics, mostly slates, quartzites and phyllites composing the Santa Ana formation of upper Triassic age, and associated with acidic extrusives also metamorphosed. These rocks are intruded by diorite and various hypabyssal rocks, notably a quartz latite-porphyry which is well developed on the eastern side of the Elsinore trough. This whole assemblage is in turn intruded by granodiorite forming stocks and a batholithic mass which is exposed along the western edge of the Santa Ana Mountains, and which includes patches of quartz monzonite and gabbro. In his work on the northwestern portion of the Elsinore quadrangle, Dudley [7] gives a similar composition to the basement complex of his area. Moore states that the material making up the old rocks of the Santa Ana Range is a complex series of slates, tuffs, andesites, granodiorites and many other rocks.

The igneous rocks of the basement complex of the entire region have thus plagioclase feldspars dominating over the orthoclase. This fact has an important bearing on the origin of some of the clays. Previous to the extensive investigations by Engel, Moore and Dudley, little was known concerning the nature of the basement complex, and most of the clays were considered to have been derived from orthoclase feldspar by its decomposition.[9] The present results, however, indicate that those clays which are derived from alteration products of the rock masses over a large distributive province came from plagioclase rather than orthoclase feldspar.

Overlying the basement complex are Cretaceous sediments, entirely unaltered. Thus the rocks which are intrusive are probably to be correlated with the Jurassic batholith of the Sierra Nevada.

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[6] Engel, Rene, Geology of the southwest quarter of the Elsinore quadrangle: Geol. Soc. Am. Bull. 43, p. 225, 1932; and unpublished thesis, Cal. Inst. Tech., 1933.

[7] Dudley, P. H., The Geology of a portion of the Perris Block, Southern California: *Abstract,* Geol. Soc. Am. Bull. 43, p. 233, 1932.

[8] Moore, B. H., Geology of the southern Santa Ana Mountains, Orange County, California: Pan. Am. G., 1 vol. vol. 54, p. 69, 1930; and unpublished thesis, Cal Inst. Tech., 1930.

[9] Linton, Robert, Tertiary clays of Southern California: Jour. Am. Ceram. Soc., vol. 11, No. 10, 1928.

Mesozoic Formations.

Aside from a series of considerably metamorphosed sediments which are, at least in part, of Triassic age as previously stated,[10] the only other part of the Mesozoic which is stratigraphically represented in this region is the Cretaceous, whose sediments overlie both the basement complex and the Triassic metamorphics with profound unconformity. The following description of the characteristics of the Cretaceous in the Santa Ana Range has been largely contributed by B. N. Moore in the course of cooperative field work.

In the Santa Ana Range province, the Cretaceous sediments fall into two main groups, the Trabuco and the Chico. The Trabuco formation, Lower Cretaceous, is a red conglomeratic and arkosic sandstone. It averages about 200 feet thick. The Trabuco, because of its red color and lithologic character, is generally considered to be continental in origin, but is thought by Moore to be marine.

The Chico, Upper Cretaceous, is undoubtedly marine, and consists of three divisions: (1) a series of well-indurated conglomeratic sandstone, much harder and lighter in color than the Trabuco, and which contains conglomeratic lenses consisting of extremely well rounded pebbles of quartzites, slates, and a considerable range of basic igneous rocks, similar to the Chico formation found elsewhere along the southern west coast; (2) an overlying series consisting of a considerable thickness of sandstone, in turn grading into several hundred feet of finely laminated shales which are blue when fresh, and gray when weathered; (3) a series, uppermost in stratigraphic position, consisting of sandstones with conglomerate and shale lenses. The total thickness of these Cretaceous beds ranges from two to three thousand feet, depending upon where the section is measured. The lithology and induration of the Chico is fairly distinctive and it is easily identified in the field. The coal mines of the Santa Ana Mountains, which were mapped by Dickerson[11] as Cretaceous, apparently are to be more properly classified in the Martinez Eocene.

So far as known, Cretaceous formations do not outcrop in the Elsinore and Temescal Valleys further southeast than Eagle Canyon, near Corona, and it is a question whether or not the Cretaceous sea extended into this province.[12]

Tertiary Formations.

Martinez—Santa Ana Range.

The Cretaceous or older formations are unconformably overlain by the Martinez formation of Eocene age. Since all of the clays in the entire district described in this paper in both the Santa Ana Range and the Elsinore-Temescal Valleys are intercalated in the Martinez, this formation is particularly important.

The Martinez of the Santa Ana Range is of continental origin in its lower part but marine in its upper. It differs from the Cretaceous in its lighter color, which is buff or light green, and its comparative lack of induration. Furthermore, it is distinguished from all the other

[10] Reed, R. D., Geology of California: Am. Assoc. Pet. Geol., 1933.

[11] Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains: U. of Cal. Pub. Geol., vol. 8, No. 11, 1914.

[12] Engel, Rene, Personal communication, 1929.

formations in the entire district by its content of a considerable amount of chlorite.

The basal bed of the formation is a coarse conglomerate which has unmistakably derived its materials from the underlying Cretaceous. It consists of well rounded pebbles, similar to those of the Chico conglomerates, admixed with boulders of conglomerates, sandstones and shales, which also exhibit Cretaceous lithologic characters, the shales being particularly distinctive. The sources of these materials must have been rather near at hand, for it is inconceivable that the shales would long resist complete breaking up in such a ball-mill as the bottoms of the streams would have been in the presence of the well rounded pebbles of the conglomerates.

The basal conglomerate grades upward into a variable thickness of subangular arkosic sandstone which in turn gives place to shales, these generally being lignitic in character. Occasional lenses of coal are found containing unbroken fossil reeds which give evidence of the material having been formed in place. The clay horizon, traceable for a distance of over eight miles, is associated with lignitic shales. The presence of the coal would seem to indicate favorable horizons for end-products of the alteration of the silicates to hydrous compounds. The sharp change in the characters of the materials within the clay horizon, in comparison to the strata above and below, is best accounted for by a sudden change in the facies of the clay bed, the scattered quartz grains indicating considerable alteration in place of material originally arkosic sandstone and conglomerate. Well-sorted and bedded marine sandstones, remarkably constant in character, overlie the shales and contain thin lenses of conglomerates resembling the basal bed. They also contain calcareous lenses with distinctive Martinez invertebrate marine fossils, including such types as *Turritella pachecoensis* Stanton.

The entire Martinez formation of the Santa Ana Range, both above and below the shales, is characterized by the presence of chlorite, which is considered to be a distinctive feature of that formation.

Martinez—Elsinore-Temescal Valley District.

The clays of the Elsinore-Temescal trough lie directly upon or very close to the basement complex. They possess a much greater thickness and diversity of ceramic use than the clays of the Santa Ana Range. All of the more valuable residual clays, so far as is known, are the result of alteration in place of rhyolitic rocks, or of subaqueously deposited volcanic breccias and conglomerates. The transported clays are derived from the alteration of materials in part volcanic previous to deposition.

The age of the non-transported rhyolites was not determined at any locality. The sedimentary materials occur in the Martinez formation. The effusive activity, giving rise to the volcanics found in connection with the clays of the sedimentary series can only be said to be pre-lower Martinez, and is not definitely set as to age.

The clays occurring in this sedimentary formation, whether residual or transported, ordinarily lie directly upon the basement complex. In the few places they overlap other sediments, which are also non-marine, these underlying beds consisting of fine-grained and well-sorted sandstones and carbonaceous shales, laid down in shallow fresh water or brackish water.

The clay horizon in the Alberhill district, consists of two members: (1) a series of red-burning residual clays comprising altered rhyolitic conglomerate and other materials which rest directly upon the schists and intrusives of the basement complex, which in a few places is sufficiently altered to be used as a low grade clay; (2) a series of much higher grade transported clays consisting of fire-clays and refractory-bond clays closely associated with carbonaceous clays and lignite. In some cases the last series only is present, resting directly upon the basement complex.

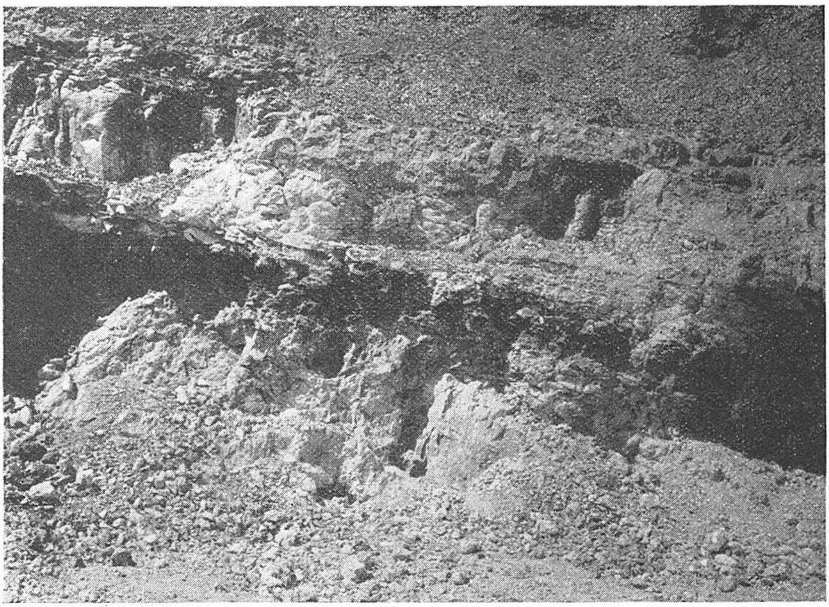

FIG. 4. Near view, illustrating character of clay and vertical variation in beds, which necessitates hand-mining methods. Plastic fire clay occurs above and below a thin bed of coal. Picture taken at outer edge of a coal lens, at upper end of Douglass pit in Alberhill district. The lignitic coal bed here shown is in some places over 8 ft. thick, and the early mining was for coal, not clay.

Above the clay horizons occur sandstones and shales possessing the same lithologic characters as the marine Martinez sediments which lie above the clay strata of the Santa Ana Range. The formations within the Elsinore-Temescal Valley trough, however, are so badly broken by post-clay faults, that correlation of the clays with other beds of a known age is rendered difficult.

The only fossils which have been found in the clays themselves consist of reeds and other plants, but these do not indicate the age of the deposits. As called to the attention of the writer by Rene Engel in the spring of 1930, in the vicinity of Lee Lake, a marine invertebrate fauna, containing *Turritella pachecoensis* Stanton and positively identified as Martinez, occurs in fine-grained sandstones overlying the clays of the Twin Springs area. A brackish water fauna collected from the bottom of a well at Terra Cotta, immediately southeast of Alberhill, consists of the pelecypod, *Cyrena*, [13] of doubtful correlating value.

The determination of the age of the clays of the area south of Twin Springs rests upon lithologic evidence permitting the correlation of the clays of Twin Springs with those of Alberhill. On the basis of the present data they are also placed as Martinez Eocene. Like the Santa Ana Range and the Twin Springs clays they were deposited in the transitional zone between marine and non-marine facies and are in themselves of brackish water origin. Abundant grains of chlorite are found throughout the stratigraphic series which contain the clays of both localities. Furthermore the clays of both provinces are associated with lignite or carbonaceous clays, and the presence of coal in Southern California is commonly assumed to denote Eocene. Also, sediments determined as Martinez by their marine fauna, occur in close proximity to the Twin Springs clay mine. The fossil horizon and the clay series below, seemingly bear a close relationship and also correspond to the marine and non-marine facies of the Martinez of the Santa Ana Range.

STRUCTURE

The structural relationships of the geologic units involved in this area indicate that the most recent form of failure of the earth's crust has been in block-faulting. In the individual clay pits, the question as to whether folding of the sedimentary formations in which the clays are intercalated is primarily dependent on and caused by faulting movements or is pre-faulting, can not be generalized upon because of conflicting evidence. In some of the clay pits evidence is seen of a period of rigorous folding preceding the block faulting which gave rise to the present mosaic, in others the major folding is unquestionably caused by strong fault movements. In those areas which are not faulted, the geological relations of the clays are rather simple.

The clays outcrop discontinuously in a horseshoe-shaped pattern whose open end points southeastward. The clay pit localities extend up the Temescal-Elsinore Valley, across on the northern end of Santa Ana Range, and southward down its western slope. The sediments form a broad northwest-southeast syncline in the Elsinore and Temescal Valleys, this structure probably being pre-faulting and locally accentuated by drag-friction to movements along the faults bordering the graben-valley depression. North of Alberhill, this syncline is further warped by folds, the axes of which are transverse to the valley axis, and is also cross-faulted [14] so that the clay horizons are repeatedly exposed.

Commercial clays also crop out immediately northwest of the Santa Ana Range fault block, in the foothills of that range, and southwest of the town of Corona. The principal locality in which these clays have been exploited is the McKnight-Corona Mine, where the clay-bearing series is broken by vertical, flat-thrust, and possibly horizontal faults, coupled with intense folding and shearing. The complexity of this structure may be explained by the fact that this locality is near the meeting point of the Chino, Whittier and Elsinore faults.

The clays of the Goat Ranch-Claymont Mine, at the northern tip of the Santa Ana Range, apparently belong to the same horizon of the

[13] Determined by Mr. W. P. Popenoe, curator of invertebrate paleontology, Calif. Inst. of Tech., on material collected by the writer in 1929.

[14] Engel, R., *Op. Cit.*, 1933.

Martinez as those of the McKnight, but exhibit no such complexity of structure. Although cut by minor faults, they rather simply dip northward down the mountain slope toward the Santa Ana River.

The beds lapping up on the westward tilted fault-block of the Santa Ana Range swing southward from the Goat Ranch locality. In the central portion of the range, the formations regularly dip westward away from the peak-forming granitic core of the mountain block. The Martinez formation is thus exposed in a broad belt which regularly parallels the contact between the basement complex and the sedimentary rocks of the Cretaceous to the east. A bed called the Serrano-El Toro clay, which belongs to the Martinez formation, crops out regularly over a considerable distance, and reveals the simplicity of the structure of the sediments of the range.

DESCRIPTION OF THE CLAY DEPOSITS

TEMESCAL—ELSINORE VALLEY DEPOSITS

The clays found in the Temescal-Elsinore valley trough make it one of the three most important clay-producing areas in the State of California as regards quality, variety of material, and tonnage mined. Production from this area has steadily increased until in normal times over 100,000 tons a year of over 30 distinct varieties of clay are mined by five major operators. This wide variety of clays is largely produced from three localities, though numberless pits, scattered throughout the valley, attest its potential resources.

That portion of the Temescal-Elsinore Valley from which clays have been taken comprises an area 30 miles long and 2 miles wide, running from the town of Corona on the north to a point a few miles below Elsinore Lake to the south. Although the clays crop out over this wide area only in irregular patches among sandstones and shales in which they are intercalated, and vary widely in each outcrop, a surprising regularity and continuity of type is found in the materials from one pit to another.

Local Geology.

The only formations which crop out in the valley are schists, quartzites, and their intrusive rocks, all of which are referred to the basement complex, and a series of Tertiary sandstones, shales, and clays. At least a part of the metamorphosed sediments are Triassic in age. They consist mainly of thinly-laminated siliceous phyllites which usually strike in a direction parallel to the valley and dip steeply. Massive quartzite beds are intercalated in these schists, which are at times extremely fissile and weather into thin flakes resembling in appearance the siliceous shale found in the Modelo or Monterey formations. The schists do not resist erosion as well as the quartzite lenses which stand out prominently as reefs. Occasionally they have been sufficiently altered to allow of their use as a low grade ceramic material.

A portion of the Tertiary sedimentaries are Martinez in age, and they resemble the outcrops of that formation in the Santa Ana Mountains. In general, however, the Martinez of the latter district appears to be somewhat better sorted, the individual beds of shales, sandstones and very infrequent conglomerates being slightly more clearly defined.

Underlying the known Martinez horizon occur a series of similar sandstones, shales and clays, also classed as Martinez, though they are thought to be for the most part continental in origin, as is the lower portion of the Martinez of the Santa Ana Mountains. They consist of well-sorted and bedded arkosic sandstones containing considerable amounts of chlorite, muscovite, and biotite, the chlorite being by far the most frequent of the micaceous minerals, and whose presence indicates the Martinez.

The continental origin of the sediments in which the clays are found is evidenced by the presence of fossil reeds, roots, and upright trunks of trees found in an impure coal bed in the clays. Brackish water fossil pelecypods, which are referred to the genus *Cyrena* were found in a bed of shale at the bottom of an old well at the abandoned tile plant at Terra Cotta, about 30 feet stratigraphically below beds containing leaf impressions collected across the road from the plant. The dip of the beds containing this fossil assemblage, if continuous, would carry them into the same series in which is intercalated the clay horizon.

The sediments overlying the clays gradually assume marine characteristics, similar to the known Martinez of the valley, which may best be studied at a fossil locality situated on the nose of the spur above the Santa Fe tracks south of the gas station at Lee Lake. The fauna include giant *Venericardia,* and *Turritella pachecoensis* Stanton.

Overlying the pre-Quaternary formations occur patches of Quaternary alluvial materials whose thickness varies between wide limits. Streams that normally flowed westward but were unable to maintain their courses across the rapidly rising central portion of the Santa Ana Range, were diverted along the base of the scarp, bevelling the softer sediments underlying the graben valley floor. In response to further diastrophism, the pattern of the streams was further changed, creating the present sag-ponds, of which Elsinore Lake is a notable example. The deposits of these former streams have been considerably dissected by intermittant creeks running out of the steep canyons normal to the valley. The materials making up these remnants consist of boulders of the igneous rocks of the basement complex, imbedded in a matrix of arkosic sandstone containing weathered feldspar, quartz, muscovite, and biotite.

In structure, the Temescal and Elsinore trough is a complex graben[15] lying between the Santa Ana and Temescal Mountains. It is broken up into slices which follow the longitudal axis of the depression, with movement observable not only between the upthrown blocks on either side but also between smaller units in the valley itself. With but a few exceptions, only the down-thrown slices within the valley are topped by sediments, the mountains on either side having suffered sufficient erosion to carry away the overlying sedimentary series, thus exposing the basement complex.

Structure within the valley, aside from the complex faulting, consists normally of a synclinal fold, the axis of which is parallel to the valley. At Alberhill, for instance, the clays dip 5° to 12° SW. down the slope of the hill but come up on the other side of the valley.

[15] Engel, Rene, Preliminary notes on the geology of Elsinore Valley: Bull. Geol. Soc. Am., vol. 39, p. 267, 1928.

The thickness of the clay member varies widely as a result of yielding to different modifications of stresses caused by adjustments of the earth's crust in response to powerful vertical and horizontal forces. Individual clay strata also thicken and thin, varying so much in thickness and in character that correlation of the individual beds between the different pits is rendered difficult.

Accurate classification and comparison, must, therefore, rest upon careful and elaborate laboratory investigation, in addition to the observations made in the field. As stated by Ross, Shannon[16] and Kerr,[17] the identification and study of the relationships of the minerals comprising any clay requires the coordinated study of chemical analyses, optical determinations, X-ray examinations and dehydration tests made on carefully selected samples. Although no such array of equipment was available in this investigation, thin sections were made

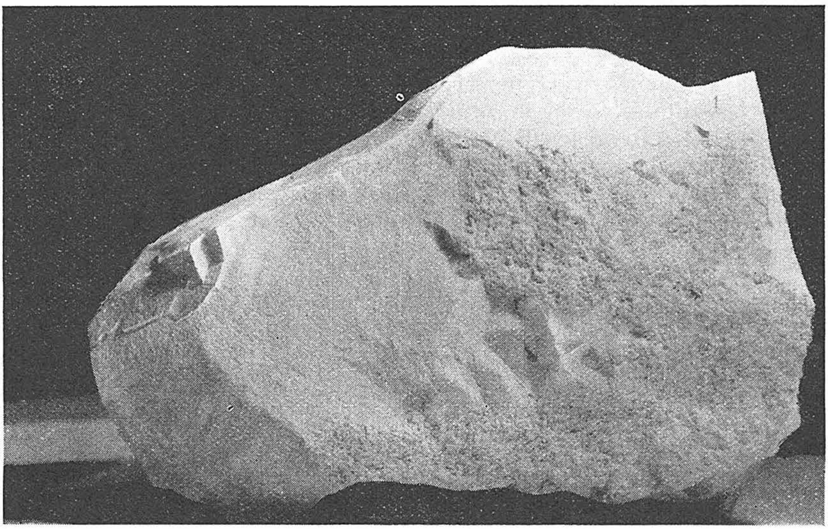

FIG. 5. Specimen of clay from upper portion of Main Tunnel stratum, showing blocky character and irregular patches of sand. The clay on the left would be classed as refractory bond, that on the right as fire clay, depending upon the amount of contained sand. Natural size.

and examined microscopically of materials representative of the principal commercial products of the district.

The clay minerals were differentiated by petrographic examination in three groups: (1) the beidellite (leverrierite)—montmorillonite group, with an index of 1.53 to 1.54 and a moderately high birefringence of .042 to .022; (2) the kaolin mineral group, with an index of 1.566 and a low birefringence of .006; and (3) the halloysite group, with a variable index of 1.47 to 1.54, depending upon the amount of essential

[16] Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays: Am. Ceram. Soc. Jour., vol. 9, 1926.

[17] Ross, C. S., and Kerr, P. F., The kaolin minerals: U. S. Geol. Surv., Prof. Paper, No. 165, 1931.

water present in the mineral, and completely isotropic. Winchell's[18] text was taken as the standard in classifications.

Alberhill District Clays.

In each complete section in the Alberhill district, three main types of clay may be distinguished. These comprise all of the principal classifications of clays found in the Southern California area. Of these, the fire-clays and refractory-bond clays are universally of the transported class and are usually associated with coal. Most of the red-burning clays are residually derived from materials in part volcanic in origin and thus may be partially bentonitic. The following description is a representative section:

1. *Yellow Top Clay.* A slightly gritty, tough, blocky clay possessing good plasticity. It has had a good deal of limonite and vegetable acid staining, and finds its chief use in sewer pipe mixtures. About 20 feet of it is exposed at the main pit at Alberhill.

2. *Main Tunnel Clay.* This is a gray-white, blocky clay, possessing semiconchoidal fracture. It contains irregular patches of fairly coarse sand, particularly in the upper portion of the beds, the lower being finer and slightly carbonaceous.

The heavy minerals in this clay found by use of the microscope includes, in order of importance: magnetite, ilmenite, apatite, zircon, and tourmaline. A thin-section of the clay reveals coarse and quite angular sand particles. Their matrix is a fine-grained clay material in which montmorillonite and a brown fibrous mineral are by far the largest of the grains seen. Members of the kaolin family and halloysite groups are also present in considerable quantity, the matrix, in general, showing great change in light intensity between illumination by ordinary light and light passed through crossed nicols. An estimation of the percentage of the materials gives quartz 10%, montmorillonite-beidellite group 25%, halloysite group 25%, kaolin group 20%. The brown fibrous material mentioned above and which constitutes about 20% of the area, is probably a replacement of cellulose.

FIG. 6. Photograph of a thin section of clay of Main Tunnel. Specimen taken from bottom portion of bed, which is less sandy and more carbonaceous than the top part. Taken with ordinary light, magn. 100 x diam.

[18] Winchell, A. N., Elements of optical mineralogy: John Wiley and Sons, 1933.

The following analyses of specimens of this clay have been furnished by the Pacific Clay Products of Los Angeles.

	Sandy Main Tunnel Per cent	Fine Main Tunnel Per cent
Ignition loss	6.97	12.34
SiO_2	72.56	59.32
Al_2O_3	18.73	25.67
Fe_2O_3	0.63	1.67
CaO	0.54	0.58
MgO	0.22	0.26
Alkalies	0.30	0.10

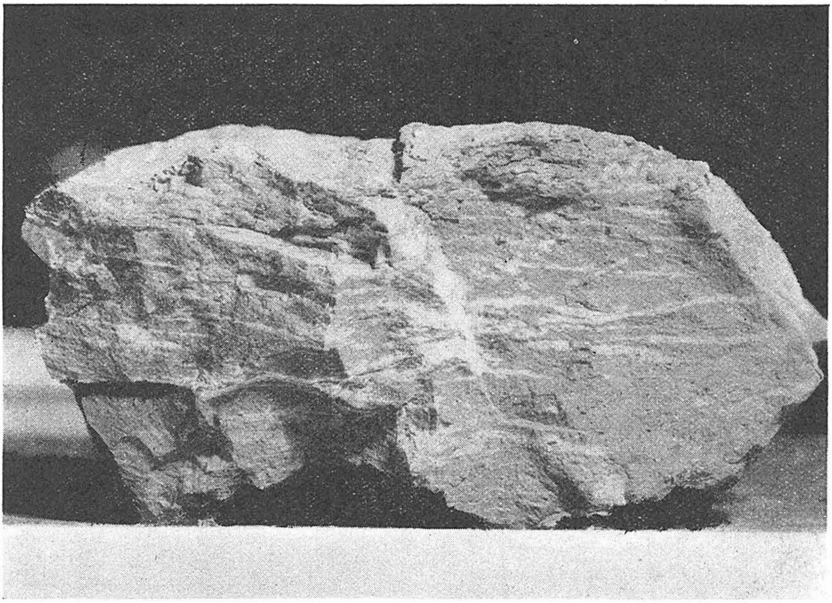

FIG. 7. Close-up of specimen of carbonaceous clay from Douglass pit which represents same horizon as lower portion of lignitic coal bed, and shows variations in the amount of finely disseminated carbonaceous material. This clay is very fine-grained, is extremely plastic, burns white and is highly refractory. Natural size.

Computation of the mineral analyses by the H. S. Washington [19] method gives the following results:

	Sandy Main Tunnel Per cent	Fine Main Tunnel Per cent
Quartz	49.5	28.6
Kaolinite	44.0	60.5
Serpentine	0.8	0.6
Limonite	0.7	2.8
Orthoclase	1.67	0.56
Anorthite	2.50	2.78
Ignition loss	0.63	3.4

[19] Washington, H. S., Chemical analysis of igneous rocks: U. S. Geol. Surv. Prof. Paper, No. 99, 1917; and Jour. Am. Ceram. Soc. vol. 1, 405, 1918.

The ignition loss in the above and following tables is due, probably, to the presence of more hydrous minerals than kaolinite and to included carbonaceous material, in this case, the finer clay being particularly carbonaceous.

The field relations of this material would seem to indicate that the original rocks whose decomposition products furnished the clay of this bed were partly derived from the phanero-crystalline basement complex of the surrounding region, and partly from rhyolitic tuffs.

A very large quantity of this type of clay is mined. At the main pit at Alberhill, it is about 35 feet in thickness. The material possesses a good working plasticity but the amount of sand within the clay cuts down the plastic strength. It fuses at the fairly high temperature of cone 30 (1650°C). It is very widely used for fire-brick, terra-cotta, art-tile, and for similar purposes.

3. Coal Stratum. As was indicated above, the clays become finer towards the base of the Main Tunnel horizon. This clay is floored by an impure coal bed, portions of which were pure enough to justify mining in the past for lignitic coal. Other portions of the bed contain sufficient clay to be utilized as such.

A chemical analysis of an argillaceous specimen follows:

	Coal Crop, Per cent
Ignition loss	33.84
SiO_2	35.35
Al_2O_3	20.74
Fe_2O_3	2.52
CaO	0.90
MgO	0.15
Alkalies	1.18

Computation of the theoretical mineral content gives the following results:

	I Per cent	II Per cent
Ignition loss	30.1	----
Quartz	5.84	8.3
Kaolinite	48.8	70.0
Serpentine	0.67	1.0
Limonite	2.84	4.05
Orthoclase	7.00	10.0
Anorthite	4.45	6.4

The contained carbonaceous materials are lost in ignition, which accounts for its high percentage in column I. In column II, the figures represent the results obtained by eliminating the ignition loss and recalculating to 100%.

The average thickness of the coal stratum as exposed in the main pit at Alberhill is about six feet. It is, however, subject to considerable variations in thickness, but the more purely lignitic portions of the bed are much more constant in this respect than the relatively incompetent argillaceous parts.

The mines at Alberhill were originally opened by the combined families of Albers and Hill for the purpose of exploiting the coal. Inasmuch as eight feet of lignitic coal is present in some places, the project was somewhat successful, in spite of the high ash content of the material. In the early days, the lack of fuels of all kinds and the poor transportation facilities made even this low grade coal valuable, the clay being simply thrown aside. In later years, however, only the Mexican laborers mined the material for their own use.

Toward the top of the hill, the coal stratum grades into a carbonaceous clay bed which, occasionally, contains 'ghost' pebbles apparently of a material originally rhyolitic. Like the Main Tunnel Clay above them, these clays are considered to be mainly transported.

The argillaceous portion of the bed possesses an excellent smooth plasticity, medium-high dry strength, and, when fired, of a white or buff color. It softens at cone 30 (1650°C) and on account of its smooth

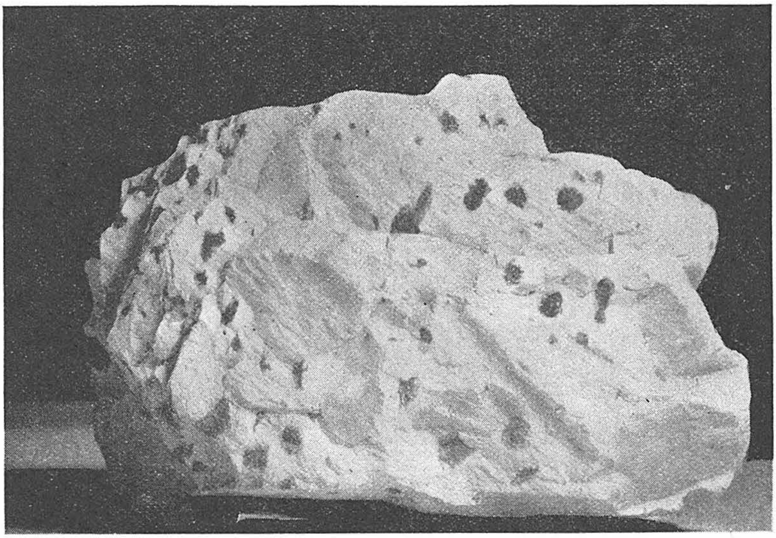

FIG. 8. Nonplastic "Bone" clay, showing angular, irregular spaced segregations of darker ferruginous material in the bone portions of the clay bed lying below the coal stratum. A possible derivation of these particles is to be seen in Fig. 10.

texture and its excellent working and fired properties, it is widely used in art tile, sagger and dry-pressed brick mixtures.

4. *Bone-Clay or SH4 Clay.* The coal is underlain by a four-foot clay bed high in alumina, which, when not pisolitic, is a plastic clay used as a ball or refractory bond material; but when pisolitic, is non-plastic and is termed 'bone.' Its peculiar texture may vary from a few sparsely distributed angular-shaped colites to round pisolites.

A microscopic thin-section of the plastic material, locally termed SH4, reveals that practically all of the materials in the clay are isotropic or nearly so. The mass is so extremely fine-grained that even in the largest grains distinction and identification is very difficult. A small amount of hydromica and chlorite was seen. Estimated mineral percentage is as follows: halloysite group 85%, quartz 3%, carbon 10% and hydromica 2%. Apatite, zircon and rutile also appear in this section.

A thin section of the bone-clay which was less plastic than the SH4, but more plastic than some varieties of bone, shows about the same birefringence as the plastic clay. However, a very weakly anisotropic mineral is present which has about the right amount of birefringence for a mineral of the kaolin group. The pisolites seem to be composed of rings of ferruginous material, but do not appear to be gibbsite, although they might contain bauxite, which absorbs iron stain readily. Estimated mineral percentage is as follows: halloysite group 80%, kaolin group 5%, 'limonite' 5%, quartz 3%, hydromica 2% and carbon 5%.

The concentric structure of the 'bone' type of clay in common geological usage indicates the presence of alumina hydrate minerals. This criterion, however, is apparently not diagnostic and should be applied with some caution, although only the high alumnia clays of this district are pisolitic.

The uses of this type of clay have already been discussed in the classification of clays. In general clay that is called 'soft bone' is ground and used in refractory wares, the 'hard bone' is calcined and incorporated as 'grog' in the same materials. Clays of the SH4 type are used as refractory-bond, or even-ball clays.

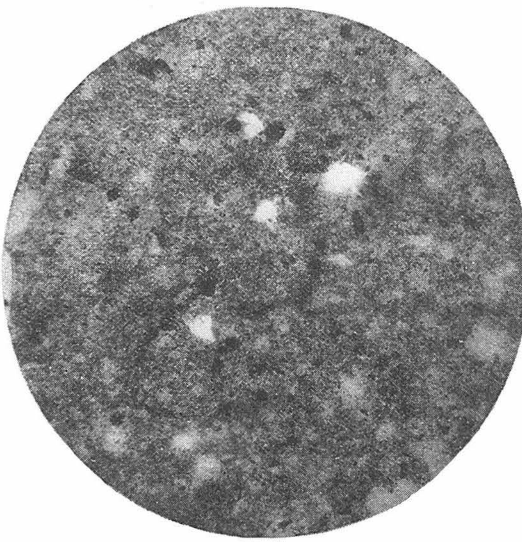

FIG. 9. Photomicrograph of "Bone" clay. The larger white patches are quartz, the dark are hydrous iron oxide. Taken with ordinary light, magn. 100 x diam.

5. Red-burning Clays. At Alberhill, the above section is usually floored by an irregular thickness of red-burning clays, some of which consist of altered phyllite schists of the basement complex, but the major portion of which are badly stained sedimentary clays. The more plastic of these residual clays are used in many types of low-vitrification wares, while the less plastic are usually cast aside. All of the red-burning clays in this area, whether transported or residual, have to compete with the more accessible clays of the Los Angeles district, all of which are of this type. As their principal market is in the Los Angeles area, transportation of them either in the raw or burned state has been one of their biggest commercial handicaps. Of late years, however, the rapid depletion of the better grades of raw materials near Los Angeles and the increase of the general quality of clay wares, have caused the Orange and Riverside County tracts to contribute more and more tonnage of this type.

Other Deposits.

Within the Alberhill district should also be included the several clay pits lying immediately across the valley. In the No. 23 and the old Sloane pits, the clays are similar in ceramic properties and geologic characteristics to the Alberhill Main Pit clays, and probably represent the same sedimentary horizon. Stratigraphically below them occur a series of argillaceous beds which are best exposed in the Pink Mottle, or No. 1 pit of the Los Angeles Brick Company. Here, a small thickness of alluvial stripping is unconformably separated from the clay beds below consisting of white 'bone' clay, below which occurs an

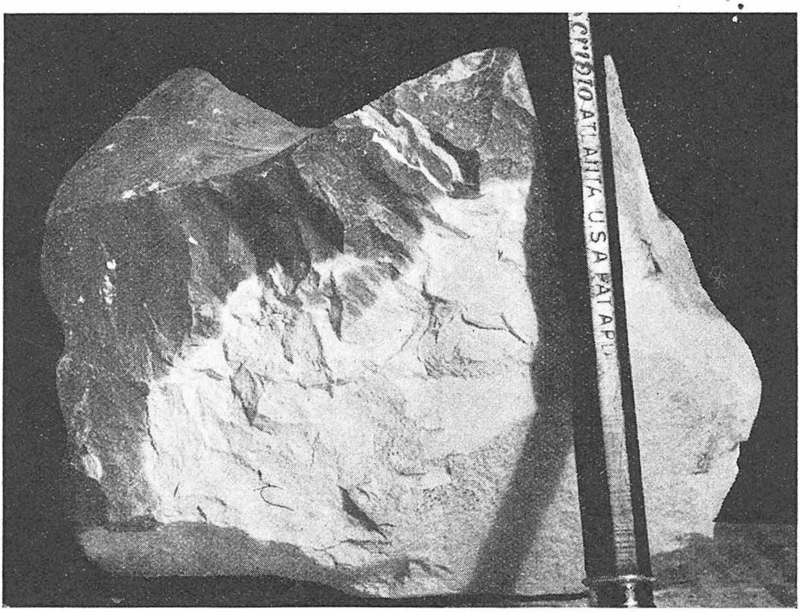

FIG. 10. "Pink Mottle" blocky clay. The dark portions of the hand specimen are red stained by hydrous iron oxide, the light is cream colored. This is an extreme plastic red burning low vitrification point clay, widely used in sewer pipe and similar mixtures. Natural size.

irregularly iron-stained clay bed locally termed 'Pink Mottle,' followed by a very ferruginous red plastic clay, which is in turn underlain by a white-burning clay followed by a great thickness of arenaceous red-burning material.

Within this pit, the purer clay of the Pink Mottle bed grades into an altered conglomerate along the strike. The pebbles and granules show a preponderance in rhyolitic material. Quartzites, schists, and a variety of other rocks are present in minor quantities. Considerable quartz sand is present which is quite angular in form. The granules of the material vary in form from angular to well-rounded, but for the most part, they are sub-angular. This conglomerate is regarded as an alluvial deposit. The large percentage of the rhyolite within the unaltered rock and its water-worn character would indicate a nearby acid lava flow. The variation from plastic clay to an almost unaltered conglomerate, with the rhyolitic pebbles still glassy and hard, was found to be sharp in most instances. Inclusions of altered conglomerate were found in the clay portion of the bed. In thin section, the clay variation of the Pink Mottle bed, when studied under the petrographic microscope, is seen to be composed of coarse, rounded 'ghost' pebbles, in which, however, but few of the original igneous textures can be seen. Estimated mineral percentage is as follows: Quartz 50%, montmorillonite-beidellite group 30%, colloidal iron 15%, halloysite 5%.

The clays of the *Harrington* pit, in the upper end of the valley, and lying on top of the Perris fault block, are very closely akin to those of the Pink Mottle pit, and undoubtedly represent the same stratigraphic horizon. The same succession is present, that is: bone, pink mottle, highly ferruginous plastic, white-burning plastic, and a huge thickness of arenaceous red-burning clay which in turn overlies the schists of the basement complex. The same irregular alteration of the rhyolite conglomerate to bentonitic clay is also well illustrated here, the field relations being exactly similar to the Pink Mottle pit to the south.

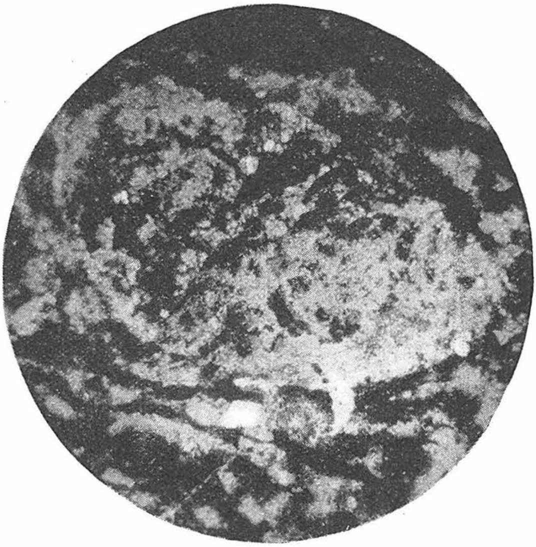

FIG. 11. Photomicrograph of "Pink Mottle" clay showing residual structures. The rounded lighter portion represents a completely altered particle which was originally laid down as a granule of rhyolite and since then has been completely altered by secondary changes. Picture taken with ordinary light, magn. 19 x diam.

South of the Harrington pit, clays are also exposed near *Twin Springs* Service Station. The clay horizon has been carried up to the surface on the northern flank of the synclinal structure, here warped by a transverse anticline. Exposures in the vicinity are poor, practically all of the area being covered by alluvial detritus which is occasionally cut through by the rejuvenated streams running out of the canyon of the Santa Ana Range. The clays occur in the bottom of one of these canyons and consist of two types: (1) a fine-grained, extremely plastic clay which is classed as refractory bond; (2) a red-mottled semi-to non-plastic clay, in some places extremely pistolitic, the entire mass being composed of very well rounded oolites. Under the microscope thin sections of this material do not appear to contain gibbsite or diaspore hydrate minerals, but is for the most part composed of an isotropic mineral which may be bauxite or of the halloysite group, with considerable amounts of 'limonite' occurring as dark concentric rings surrounding the pistolites, as staining and replacement.

The only pit south of the town of Elsinore which regularly produces clays, so far as the writer knows, is a small mine called the *Wildomar Kaolin* deposit. Its importance in this discussion lies in the fact that the clays are residual in origin. This deposit lies 2.6 miles southwest of Wildomar on the main highway to Murrieta, and is only one of several outcrops.

At this place, the beds strike N. 37° W. and dip 26° to the south. They plunge under the alluvium of the valley, but were not observed coming up on the other side. These beds lap up on the foothills on the eastern side of the valley, and are terminated by a fault which separates the bentonite beds from the basement complex of the hills to the east. The clays are clearly derived from acid-lava

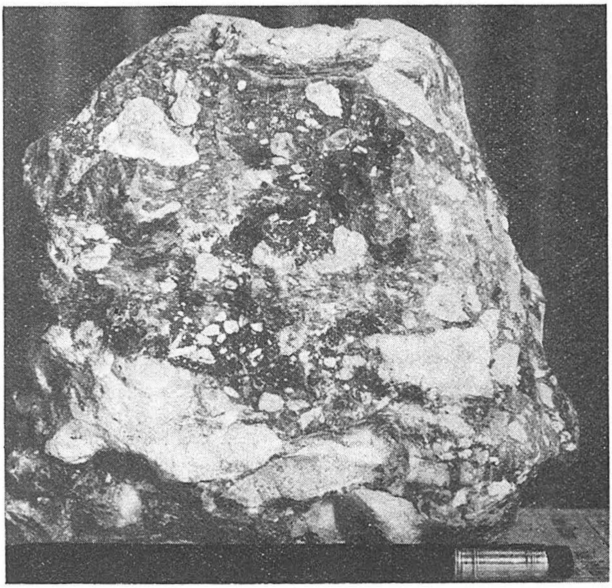

FIG. 12. "Pink Mottle" clay from Harrington pit. This material is a partially altered rhyolite-conglomerate, the pebbles of which in some portions of the bed are still vitrified and glassy, in other portions are altered to clay and in still others have lost all individual characteristics from the matrix and present an even blocky appearance. One-half natural size.

flows, which have been altered in place to their present condition. Beds consisting of altered rhyolites and rhyliotic tuffs, pumiceous and agglomeratic, make up the section. The beds break very easily along the bedding planes of the flows and also along lines of flow-structure. Advantage is taken in mining of that fact. While this material has been very considerably altered from its original condition, divitrification and alteration has not proceeded nearly so far as in the case of the Pink Mottle bed.

A thin section of this material, taken across the flow structure, shows under the microscope characteristic rhyolitic texture, such as

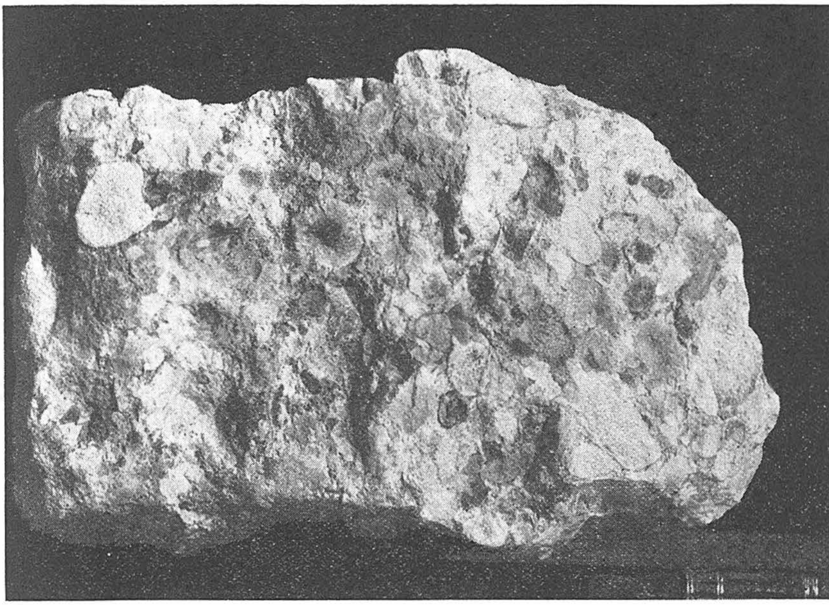

FIG. 13. Hand specimen of material from same bed as of Fig. 10, showing possible derivation of angular pisolites in some bone clays of district. In the upper left center of photograph, a concentration of the ferruginous material within one of the former rhyolite pebbles has given rise to an angular pisolite. Persistence of these features, however, through complete alteration of the conglomerate to the type of clay as in Fig. 12 was not seen.

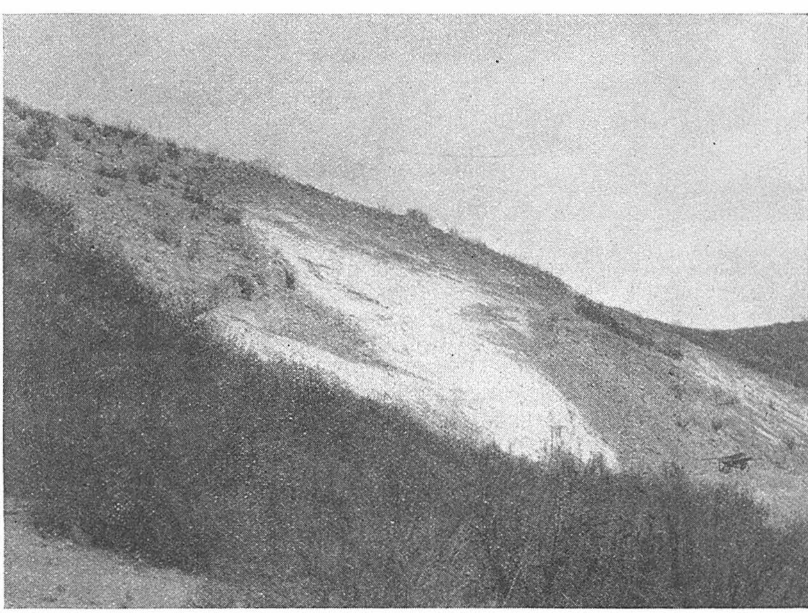

FIG. 14. Wildomar pit towards the southeast, showing remarkably well developed parting within the successive volcanic flows.

stringers of glass, portions of bubbles and a few phenocrysts. With polarized light, only corroded and somewhat oriented quartz phenocrysts can be observed, the matrix being isotropic glass. The extremely acid nature of the rock is shown by the presence of this type of phenocrysts, and by following ultimate chemical analysis from the laboratory records of the Pacific Clay Products of Los Angeles:

	Wildomar Clay Per Cent
Ignition loss	7.78
SiO_2	70.14
Al_2O_3	14.97
Fe_2O_3	1.61
CaO	1.58
MgO	.09
Alkalies	3.94

FIG. 15. Hand specimen of Wildomar clay, showing agglomerate and the finer, cooling cracked, more glassy portion of the base of the next flow at the top of the photograph. Natural size.

The comparative lack of alteration of the material is brought out by its high alkali content. It is even better shown in the results of computation by the H. S. Washington method of obtaining the theoretical mineralogical content of clay from the ultimate analysis, given as follows:

	Wildomar Clay Per Cent
Quartz	42.48
Kaolinite	19.7
Limonite	2.16
Serpentine	2.21
Orthoclase	23.2
Anorthite	7.9
Free water	4.7

The clay is non-plastic and is used as a filler in various mixtures, particularly in stoneware. It burns to a brown color at a rather low temperature but possesses a very low shrinkage. Considerable quantities of this material have been mined by stripping and hand-loading methods and also by a shaft sunk to follow the bed beneath the valley floor.

Residual clays are found at a commercially unimportant but a scientifically interesting deposit immediately across the canyon northeast of the Douglass pit at Alberhill. They represent alteration of hypabyssal quartz-latite porphyry which intruded the metamporphics of the basement complex. Subsequent alteration of the igneous rock has been so profound as to make this clay intermediate in decomposition between the residual clays of the Wildomar pit and the softer portions of the Pink Mottle bed of the Pink Mottle and the Harrington pits. These residual clays, all of which unquestionably represent alteration in place, exhibit three stages of progressive alteration, just as the same variation is found within the above mentioned Pink Mottle bed.

McKNIGHT—CORONA CLAYS

Local Geology.

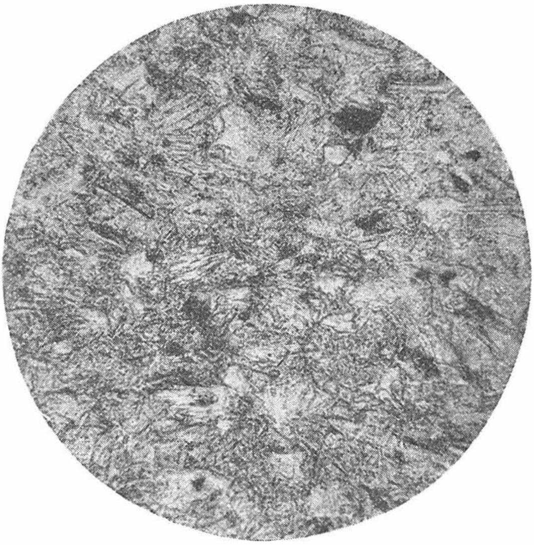

FIG. 16. Photomicrograph of Wildomar clay showing remarkably well developed tuffaceous structures, such as stringers of glass, broken shells of bubbles, etc. Taken with ordinary light, magn. 100 x diam.

The elongated triangle which lies between the Chino fault, the Whittier fault and the Santa Ana Canyon, is very complicated structurally and increased in complexity towards the apex of the triangle on the south, where the Chino and Whittier faults merge and join into the Elsinore fault. The trace of the Whittier fault bounds the south side of the Puente Hills, crosses Santa Ana Canyon, turns southeastward, and continues along the boundary of the main block of the range as the Elsinore fault. The Chino fault, the existence of which has been the subject of considerable discussion among geologists, also bounds the Puente Hills, but on the eastern side, and continues southward, bounding the foothills to the south of the Santa Ana River, and eventually joining the Whittier-Elsinore fracture-zone.

Both of these fault systems are primarily reverse faults in character and indicate a considerable shortening of the earth's crust. Compressional forces, producing thrust movements along reverse-faults in sediments, normally result in folding and faulting structures in either the lower or upper block which parallels the zone of fracture. Examination of the folds and faults of the triangular block together with its continuation, the Puente Hills, shows that those structures which give evidence of shortening are, in general, perpendicular to the axis or bisectrix of the Y thus produced. This fact would seem to indicate that the Chino-Corona and the Santa Ana Range blocks moved northward with respect to the Puente Hills, although a drag in the folds in the vicinity of the Chino fault block indicates that there may have been differential horizontal movement corresponding to the displacement of the San Andreas rift. Thus the Puente Hills block may be acting as an incompetent mass between competent east-west blocks bounding the north side of the Los Angeles Basin and the blocks to the south.

The steep rise of the land surface from the head of the alluvial fans above the Corona plain to Sierra Peak appears to be due to a series of step-faults. Four main step-blocks may be distinguished, and each of the four blocks is topped by successively older formations, according to their position relative to the core of the range. On the bottom block, which is separated from the alluvial-covered block by a fault, lie sandstones, shale, and conglomerate beds of Martinez age. They are separated from the Cretaceous sandstones and shales of the next block by a fault-scarp. These Cretaceous sediments of the second step abut the granodiorites and metamorphics of the basement complex in fault contact on their western side. To the west of this belt of crystalline rocks, the Cretaceous beds again outcrop, the relationships being a depositional contact. These sediments have a fairly strong westward dip and in turn are faulted against the crystalline rocks of the crest of the range.

In addition to the northwest-southeast fracture-zones, the steps are further cut by innumerable cross faults which are roughly perpendicular to the major structure. These cross-fractures are predominantly reverse in character, frequently having dips as low as 20° or less. While the movement along the individual zones of slippage is small, the total shortening would aggregate many feet.

The axes of the folds of the sediments in the triangle also trend northeast-southwest. The clays lie between relatively competent beds of sandstone and conglomerate and form a very favorable plane of slippage, along which major and minor movements have taken place when the attitude of the beds was favorable. At the McKnight mine, for instance, just south of Tin Mine Canyon, the sedimentary series strike N 65° E and dip 25° to the south. This attitude has apparently placed the clay bed in a position favorable for thrust-slippage, for it has suffered considerably.

The McKnight clay beds are intercalated in the sandstones and conglomerates of the Martinez formation which is exposed in the first step-fault block. The clay beds represent the end product of a process of deposition of increasingly fine material and grade downward in the section to arkosic sandstones which in turn pass into coarser and coarser conglomerates. These conglomerates are composed of well-rounded pebbles of quartzites, fine-grained intrusive rocks, intermediate in composition, schists, and infrequently older re-worked conglomerates, sandstones, and shales. The matrix is a coarse, arkosic sandstone containing considerable amounts of chlorite, biotite and muscovite. The conglomerates grade into sandstones and shales above, the mineral content remaining about the same. There is no doubt that a considerable portion of these materials were derived from Cretaceous sediments, and that their source was not far away.

Above the shales and clays lie massive sandstones in which a Martinez Eocene invertebrate fauna was found, including such forms as giant *Venericardia* and *Turritella pachecoensis* Stanton. These fossils were found almost immediately above the clay horizon.

Description of the Clays.

As previously indicated, the clays lie in a more or less plastic zone, and the transition from sandstone to clay to sandstone is not abrupt. The sandstones below are green or buff, but as they approach the clays, they become darker in color, passing into shades of gray. The clay bed is overlain by shales which are universally stained red or pink by iron-oxide, in part deposited with the sediments or derived from the immediate beds mainly leached from the overlying sediments and deposited on top of the impermeable layer of clays. These stained shales were used in the past as red-burning low-vitrification clays, because they were sufficiently argillaceous. They are, however, no longer exploited.

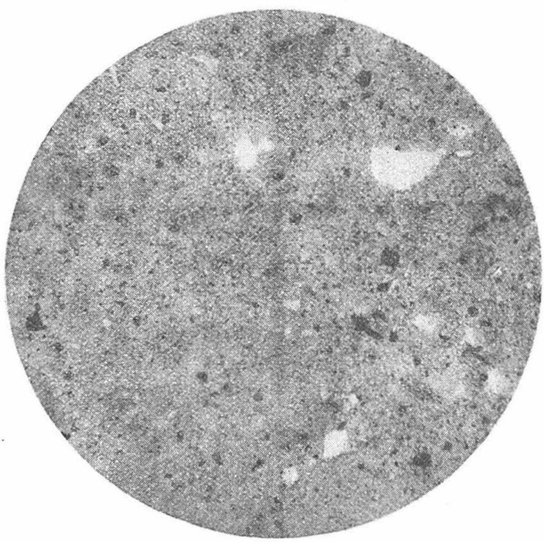

FIG. 17. Photomicrograph of the McKnight flint fire clay showing its texture. Taken with ordinary light, magn. 100 x diam.

The major portion of the clay stratum is composed of a flint fire-clay, more or less sandy and well-indurated, which contains a variable amount of gray or black finely disseminated carbon. In places the carbonaceous material is concentrated in lenses and pockets of coal, in which occasional lenses of pisolitic bone-clay may be found. In other places, very little carbon is present, and lenticular bodies of an extremely hard light-gray fire-clay may occur with or without the regular black fire-clay. The white or light-gray clays lack the toughness of the darker portions of the bed, contain considerablely less quartz sand and break, when exposed to the air, with conchoidal fracture.

Under the binocular miscoscope, the coarse sand is seen to be made up almost entirely of clear, well-rounded quartz, and infrequent, badly altered feldspar minerals. Heavy minerals found, in order of frequency, include the following:

1. Ilmenite, frequently showing traces of rhombohedral forms.
2. Magnetite, silver gray in color.
3. Tourmaline, light brown, but only slightly pleochroic.
4. Sphalerite (?) with good cleavage, black, opaque, and resinous.

A thin section of a specimen of fire-clay, when examined under the petrographic microscope, showed an extremely fine-grained material, with the larger particles of quartz making up about 30% of the slide. Estimated mineral percentage of the matrix is as follows: kaolin group 35%, montmorillonite-beidellite group 30%, halloysite group 4% and chlorite about 1%.

The following analyses were obtained from the Pacific Clay Products, who own and operate the McKnight Mine:

	Black McKnight fire-clay Per cent	Red McKnight red-burning Per cent
Ignition loss	10.62	8.73
$SioO_2$	57.38	63.86
Al_2O_3	27.62	21.52
Fe_2O_3	2.06	4.12
CaO	1.90	.24
MgO	.11	.09
Alkalies	.13	.83

Calculation by the H. S. Washington method of the mineral content, ignition loss set aside, gives the clay the following theoretical composition:

	Black McKnight fire-clay Per cent	Red McKnight red-burning Per cent
Quartz	23.2	33.15
Kaolinite	60.10	52.50
Serpentine	2.50	.19
Limonite	2.43	4.20
Albite	1.25	7.20
Anorthite	9.45	1.20
Free-water	1.7	.70

On account of the predominance of plagioclase in the original rocks of the basement complex, from which this clay was derived and later deposited under transitional to shallow marine conditions, the alkali content has been calculated as soda.

The fire-clay has a fair plasticity, a medium low-dry strength and is granular and friable when dry. Steel hardness is developed only at a very high temperature. The softening point is cone 33 (1745° C.). It has a low shrinkage due to the amount of sand contained in it. It possesses excellent hand-moulding qualities and is largely used for that purpose.

The Red McKnight Red-burning clay was formerly used as an ingredient in sewer pipe and brick mixtures. It has a better plasticity than the fire-clay although it is weakened by the large amount of sand. Fingernail-hardness develops at cone 010 and steel hardness at cone 7. It has not been mined for a number of years, the previous large production ceasing when the clay products plant at Corona burned down.

The McKnight mine is one of the oldest clay-producing properties in southern California, operations having begun as early as 1890. Most of the mining is carried on underground, overhead stoping methods being employed. Minor faulting has so broken up the fire-clay stratum that the spur in which the mine is located is literally honey-combed by the tunnels and raises driven into it by the exploiters in an effort to find and extract the clays.

GOAT RANCH OR CLAYMONT CLAYS

Local Geology.

A valuable deposit of clay is mined on the northern tip of the Santa Ana Range by the Gladding McBean Company, and the property is known as the Goat Ranch or Claymont mine. Clays in the vicinity of Goat Ranch have been mapped by English[20] as Cretaceous, therefore subsequent writers have assumed that all of the clays belong to that geological period. English, however, may have referred to some long-since abandoned pits, for the clays now mined belong to an entirely different geological formation. Stratigraphic relationships of the horizons now producing, indicate that these clays are Martinez Eocene in age, and not earlier. The lignitic shales in which the flint fire-clay bed is intercalated, grade downward into a coarse sandstone unconformably deposited over the Cretaceous, Chico, series. The Chico here exposed consists of a bed of coarse conglomerate overlying a finely laminated reddish-black shale, aggregating at least 1000 feet in thickness. The actual contact of coarse sandstone with the conglomerate was not examined, but the attitudes of the underlying conglomerates appear to have a slightly greater dip in the vicinity of the mine. Although no diagnostic fossils were found in either the upper or lower member, there is no doubt that the shales are Cretaceous in age, for the middle portion of that formation, to which the shales belong, is unique in its lithologic character. The material above the conglomerates, on the other hand, strongly resembles the Martinez of the Santa Ana Mountains.

The basal conglomerate, although coarser, of the Martinez formation as exposed in Silverado Canyon, is exactly like the coarse sandstone in general appearance and induration, and an analogous bed in the Cretaceous is not to be found. The shale and sandstone pebbles included in the conglomerate are similar in the two localities, and the assemblage of materials differ only in proportion, the bed at Silverado Canyon having the more sedimentary pebbles. It also possesses a striking resemblance to the conglomerate which underlies the McKnight fire-clay.

English[21] states that the presence of glauconite is characteristic of the Martinez of the northern end of the Santa Ana Mountains. The present investigation revealed no glauconite, but instead a large amount of chlorite, which, when abundant seems to be confined to the Martinez of the entire Santa Ana Mountains.

The classification of the age of the clays as Martinez Eocene, rather than Cretaceous, as they have heretofore been considered, is further strengthened by the remarkable similarity in manner of occurrence, mineral assemblage, and in ceramic properties between the Corona-McKnight and the Goat Ranch clays, and also due to the

[20] English, W. A., Geology and oil resources of the Puente Hills, Southern California: U. S. Geol. Surv., Bull. 768, 1926.
[21] English, W. A., *Op. Cit.*, p. 12.

presence of *ostrea* beds towards the middle of the section which resembles the beds near Twin Springs.

If this assumption is true, a strong unconformity should exist below the conglomerate member. A normal section of the Cretaceous of the northern Santa Ana Mountains shows that the formation is composed of three broad members as follows: (1) a top layer of sandstones and conglomerate which is about 700 feet thick; (2) a section of dark-colored finely laminated shales, about 1500 feet thick; and (3) another layer of sandstones and conglomerates, which aggregate about 800 feet in thickness. Inasmuch as the greater part of the top sandstone member is completely missing, a hiatus is indicated sufficient for uplift and erosion of at least 600 feet of material.

A northerly-dipping monocline forms the principal structure in the central portion of the extreme northern end of the Santa Ana Range, in which the Cretaceous and Martinez sediments dip steeply away from the basement complex of the range. In the vicinity of the Goat Ranch, the beds nearly parallel the long surface which runs down toward the Santa Ana River. On the south end of the Claymont property a hard resistant bed of flint fire-clay forms the capping of the hills extending from Sierra Peak toward Santa Ana Canyon. The dip of the beds take them below the surface at a variable distance from the west line.

FIG. 18. Photomicrograph of the Goat Ranch flint fire clay, showing comparatively coarse texture. The fibrous chlorite at upper edge may be clinochlorite. Taken with ordinary light, magn. 100 x diam.

Description of the Clays.

Of the two types of clay which occur on the property, the flint fire-clay or marine clay which is mined by tunnel in the canyon is by far the most valuable. It is a persistent bed of hard black clay containing considerable amounts of carbon and lies stratigraphically above the lighter colored clay exposed on the edge. Like the McKnight clay bed, it represents the end-product of a process of deposition of increasingly finer material. Its average thickness varies from four to seven feet. Lignitic coal lenses occur above the clay bed, which occasionally itself takes on a lignitic character. On top of the ridge, however, the clay contains practically no carbon and is light-gray in color. Quartz sand is disseminated throughout the clay and is also concentrated in lenses, which in places contain too large a proportion of it to be valuable.

Below is found an extremely pisolitic 'bone' clay, which has apparently not been mined.

A thin-section of a specimen of the flint fire-clay from the top of the ridge shows under the microscope that it is composed of about 45% quartz, 40% kaolin group minerals, 12% chlorite and 3% minerals of the halloysite group. The grains of quartz are by far the largest of the minerals in the section. The chlorite, which is light-brown and pleochroic, is in the form of long thin-fibrous masses, with a birefringence of about .015.

The clays of this deposit are used for the same purposes as those of the McKnight-Corona. Since they have a high fusion temperature (cone 34 or 1755° C.), they are principally used in making high-refractory fire-brick. Some of the shales which burn red and vitrify at a low temperature by reason of their high iron content have been used for common brick and tile but they can not now be mined in competition with the more easily accessible and better clays of Temescal Valley. In mining the fire-clay bed, the Gladding-McBean Company, who operate the property, run tunnels up the dip of the bed from the head of the canyon, tram the clay to chutes which carry the material to loading bunkers at the canyon bottom. Practically all of the clays are used at the Alberhill plant of the company. No figures on the yearly tonnage mined have been secured.

SERRANO OR EL TORO CLAYS

The Serrano clay bed outcrops along the west-central portion of the Santa Ana Mountains from Trabuco to Silverado Creeks, just east of the Modjeska Road. The nearest town is El Toro, which lies 10 to 15 miles from the various mines. Since the principal producing mine is on the Serrano Ranch, the clays herein described may be called the Serrano, or El Toro clays.

Local Geology.

The sandstones in which the Serrano beds are intercalated have been mapped as Vaqueros Miocene by previous workers[22] in the field. In the course of the present investigation, however, it was found that the formation more closely resembled the Martinez in the other portions of the Santa Ana Range. The abundance of chlorite and the induration of the material were notable criteria which did not agree with the definitely known Vaqueros formations. In the course of mapping the areal extent of the bed, both Dr. Bernard Moore, who also worked in the area, and the writer traced the clays with only one short break in continuity, into a series of beds which were established as Martinez on the basis of an invertebrate funa found very close to the clay exposure in Silverado Canyon.

The Martinez formation of the Santa Ana Mountains is, in the main, made up of massive sandstones which when fresh are white or green, depending upon the amount of chlorite present, but which upon weathering become a uniform buff. These sandstones overlie a basal bed of conglomerate. The conglomerate bed in Silverado Canyon is

[22] Dickerson, R. E., The Martinez and Tejon Eocene and associated formations of the Santa Ana Mountains: U. of Cal. Pub. Geol., vol. 8, No. 11, 1914.

FIG. 19. Outcrop of the Serrano clay bed looking southeast from the top pit of the Serrano mine. The heavy white line denotes the surface intersection of the clay bed which lies within the Martinez formation. The comparatively gentle western slope of the Santa Ana tilted block is evident. *Photo by B. N. Moore.*

FIG. 20. Close-up of the Serrano pit looking in the opposite direction. The beds at this point are almost vertical. Dark green shale lies at the base of the bed to the right and a localy resistant bed of buff sandstone overlies the clay stratum. Modjeska grade is in the distance.

made up of pebbles of quartzite, dacite, slate, shale, and sandstones, which have apparently been largely derived from the sandstones, shales, and conglomerates of the Cretaceous, and this character is typical of the bed wherever it was observed. The pebbles average one to two inches in diameter and the harder materials are well-rounded. The matrix is an arkosic sand in which considerable amounts of chlorite are present.

Description of the Clays.

The clay bed constitutes an easily mappable unit and can readily be distinguished from the remainder of the Martinez by reason of its plasticity, white or pink color, and the ease of erosion in contrast to the harder buff sandstones. The bed was readily traced for almost eight miles, its outcrop being almost a continuous line and only broken by minor faulting. The largest displacement seen occurs along a northwest-southeast fault which runs through the divide just north of the Serrano mine. The beds in this vicinity have a dip of 75° to the south and a strike of N. 65° W. The fault plane is very close to vertical and has a strike of N. 75° W. Apparently the existing field relations were brought about by vertical movement along the fault with the northeast block relatively rising with respect to the other block. This was followed by erosion to the present level.

FIG. 21. Bottom pit at Serrano mine, showing massive, blocky character of the clay bed, which dips 75° away from the observer. The contact between the Serrano clay and the underlying green shale can be seen on either side of the truck-way, at the sides of the picture. In mining practice, the lower portion of the face is blasted out and the upper portion of the cliff is then caved.

The clay bed lies about 2200 feet above the base of the Martinez at Trabuco Creek, about 200 feet above at the Santiago-Aliso divide, and about 250 feet above in Silverado Canyon, and is here 150 feet above a series of lignitic shales and clays which are believed to represent nearly the same horizon as the Goat Ranch materials. Although the clay beds of these two localities may not be continuous nor of exactly the same horizon, they certainly approach each other closely in the stratigraphic series and were laid down under similar conditions.

The main mass of the bed of fine, white sandstone of which the clay bed forms the base, contains little alteration products and is composed mainly of quartz. A sharp increase in the amount of clay in the matrix of the sandstones may be detected at the upper contact of the clay bed. Immediately below the bed lies a fine-grained dark-green chloritic shale, which, when weathered, is dark-red. It overlies lenses of lignitic shales which vary widely in size and content of carbonaceous material. In Silverado Canyon is a coal lens of sufficient purity that the Southern Pacific Railway once mined it before the discovery of oil. This coal outcrop was considered as Cretaceous by Dickerson and others but is here more correctly assigned to the Martinez. A sharp contact exists between the green shale and the over-

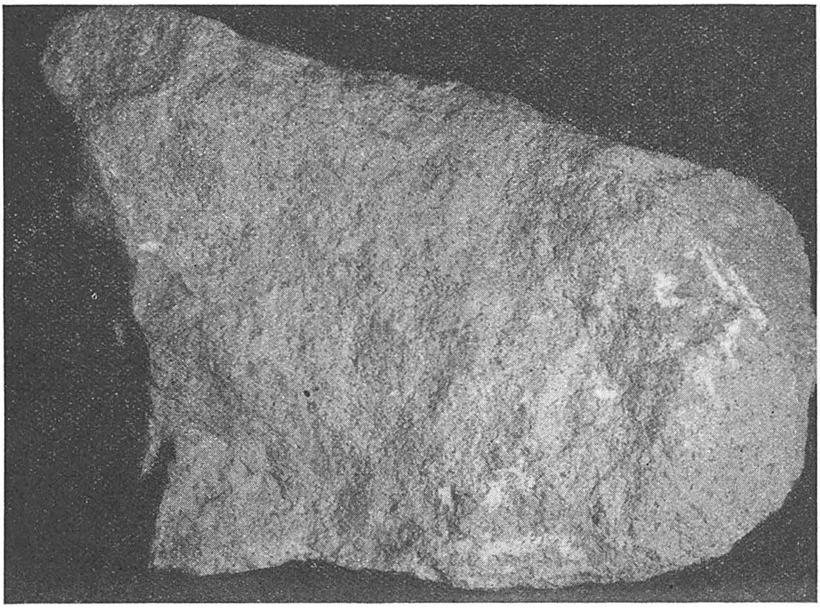

FIG. 22. Hand specimen of Serrano clay, illustrating ccomparatively coarse sand particles irregularly embedded in the matrix of fine clay. Natural size.

lying clay bed, and only small amounts of chlorite are found within the clay bed itself.

Almost universally the upper portion of the clay stratum is stained various shades of pink or red, the iron-oxide having apparently been derived from the sandstones above. The main part of the clay bed is usually gray-white, but, with inclusions of carbonaceous material, or ferric oxide, it may vary widely in color along the strike.

The remarkable continuity of the clay horizon, and its sharp differentiation from the sediments in which it is intercalated, indicate a sudden and temporary change in the materials laid down during that portion of Martinez time. The original material of the bed is considered to have been deposited as an altered arkose because of the irregularly scattered sand particles in the clay matrix, and to have been further altered to its present state since deposition. The field relationships suggest that the clays are in part bentonitic, and that a portion of the materials whose decomposition products gave rise to the clays is volcanic in origin, so that this horizon may be a near correlative of the Alberhill ceramic materials. Microscopic examination, however, fails to reveal any positive criteria tending to prove such a derivation, although a few features are suggestive.

The material of the bed consists of grains of slightly impure sand, imbedded in a matrix of hydrous oxides and silicates of iron and alumina. Microscopic examination shows the coarse particles to be clear quartz, which is rounded, subangular, or infrequently, angular. Altered feldspar grains are also present in minor quantities and are too much kaolinized for exact determination. Chlorite, and in minor amounts, biotite and muscovite, were also found. Heavy minerals present, in order of frequency, are: ilmenite, in irregular grains partially pocketed and coated by leucoxene; tourmaline, yellowish irregular grains and prisms; staurolite, in light brown irregular grains; magnetite, somewhat altered; almandite, light brown, irregular in shape; and pyrite, badly altered but frequently with some suggestion of isometric form.

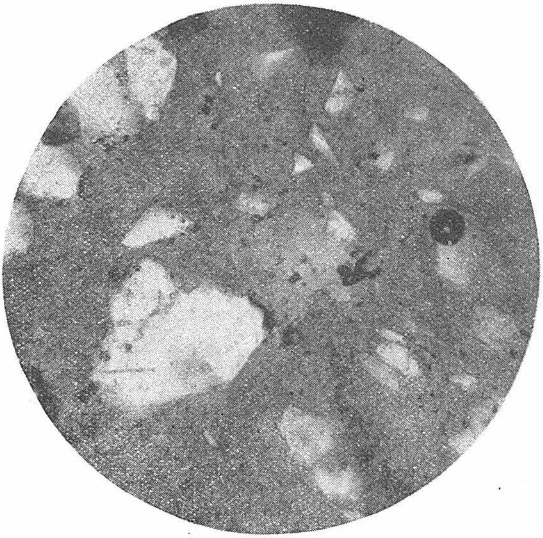

FIG. 23. Photomicrograph of Serrano clay, showing texture, and the relation of the quartz to its matrix. Taken with ordinary light, magn. 100 x diam.

Thin-sections of the Serrano clay show under the microscope that there is a large discrepancy between the sand portions and their extremely fine matrix. The material is composed of about 55% quartz, 25% montmorillonite-beidellite, 15% halloysite group and 5% chlorite. One or two structures were found which would suggest a partial tuffaceous origin, although they were not clear enough to positively identify the material as such.

The following chemical analyses were obtained from the laboratory records of the Pacific Clay Products of Los Angeles, who operate the Serrano mine:

	Serrano Plastic Per cent	Serrano Average Per cent	Serrano Washed Per cent
Ignition loss	11.57	8.42	14.02
SiO_2	54.08	65.94	47.44
Al_2O_3	30.00	22.65	36.06
Fe_2O_3	2.57	1.41	2.40
CaO	.26	.10	None
MgO	.45	.26	None
Alkalies	.23	.21	.14

The analysis of Serrano Plastic was of a specimen selected from a lens containing more clay and less quartz than the average. Serrano Average is the ordinary run of the mine material. Serrano Washed is the clay after most of the quartz has been removed by washing.

Computation of the minerals of the clay from the ultimate analyses by the H. S. Washington method gives the following:

	Serrano Plastic Per cent	Serrano Average Per cent	Serrano Washed Per cent
Quartz	18.00	38.40	4.83
Kaolinite	73.1	59.1	90.5
Serpentine	1.0	.57	None
Limonite	3.0	1.68	2.9
Albite	1.25	1.12	.77
Anorthite	4.19	1.05	None
Free water	.60	.23	1.3

A variable portion of the bed is stained by iron-oxide solution, usually consituting the upper third to half of the clay stratum. When iron-oxide is contained in sufficient amounts visibly to stain the clay, it lowers the fusion point and colors the burned ware, so that the material can only be used for cheaper products. Thus little of this clay is used.

The white clays are used in face-brick and low-grade fire-brick mixtures. When washed, they may be used for china clays and slip clays, although but little material has ever been employed in these capacities owing to the cost of preparation. Partially washed and ground, they can be and are used for white stoneware products. The natural clay burns buff at cone 10 (1260° C.) and has a moderate shrinkage at that temperature. The washed clay burns white at a high temperature, but becomes darker when cone 20 to 26 (1530–1595° C.) is reached. As would be suspected, the washed clay has a high shrinkage and a tendency to warp.

Production varies considerably, the highest tonnage recorded being in 1928, when about 10,000 tons were mined. The cost is high because the clay must be hauled by truck to El Toro, as much as ten miles distant, loaded into railway cars and shipped from there to the Los Angeles district.

Important clays also occur in Trabuco Creek on the Santa Margarita Ranch. These comprise a wide range of ceramic types and are similar to the Alberhill and Serrano transported fire-clays. They were also deposited within the Martinez formation in a transitional zone between marine and continental areas of sedimentation.

SUMMARY AND CONCLUSIONS

Bordering the Santa Ana Range in Riverside and Orange Counties are found clays which make this area one of the three major-producing districts in California. These clays comprise more than 30 different ceramic types, but may broadly be classified into fire-clays, refractory-bond clays, and red-burning clays according to commercial use, and into residual and transported types according to origin.

In the residual clays, a few of the extremely low-grade deposits are considered to have been derived from the decomposition of phyllites

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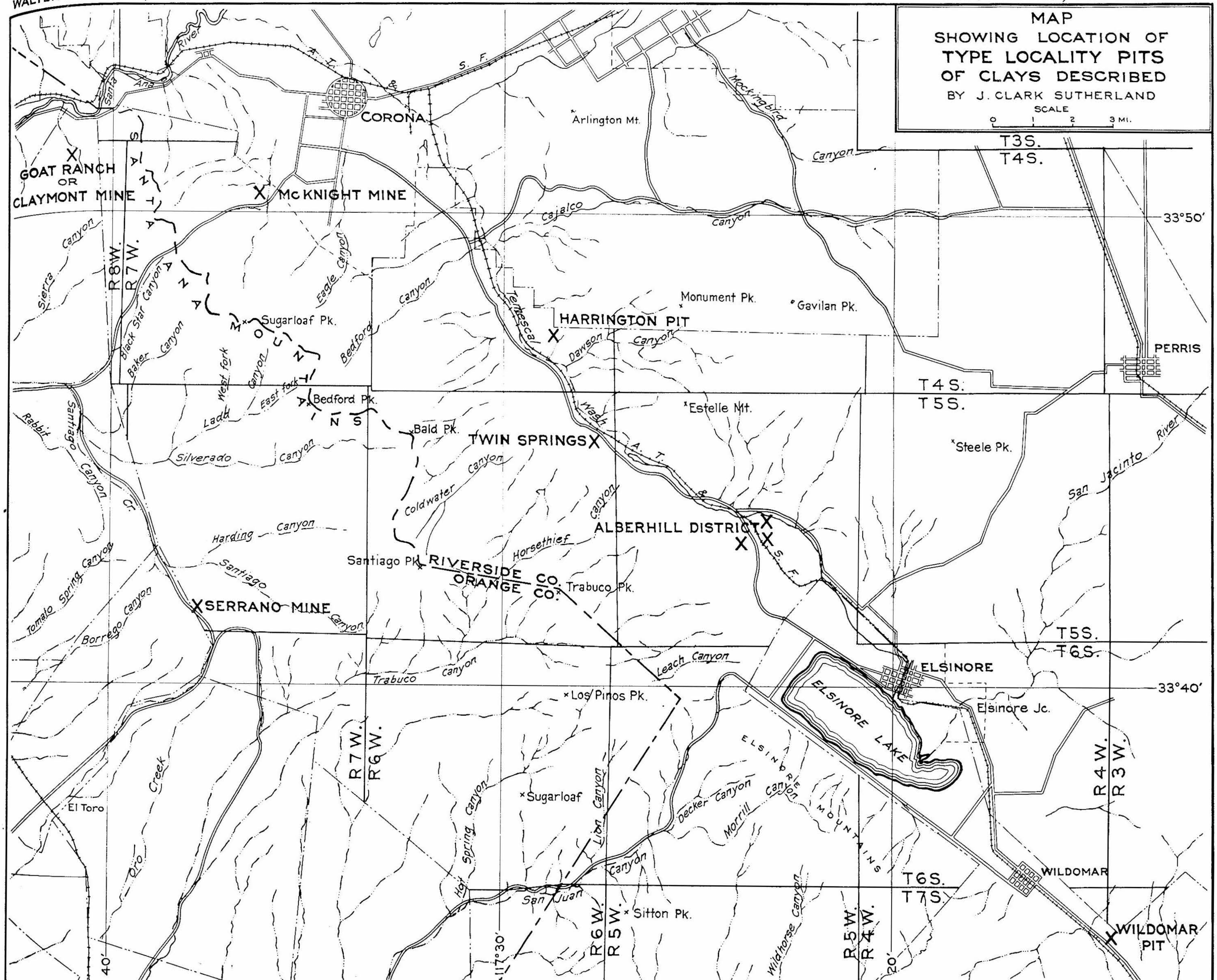
PLATE I.



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of the basement complex, but the others are thought to represent the product of a process of devitrification and alteration of aphanitic and igneous material, mostly rhyolitic, and thus to be partially bentonitic. Further, within this class are found some deposits in which the volcanics have been altered *in situ*, but most of the commercially important clays of this type are the result of the alteration of the rhyolitic portions of a sedimentary series of conglomerates. These conglomerates occur in close conjunction with clays of the transported class, which are mostly derived by alteration of the feldspars of the plutonic rocks, but which in minor amounts, may have been derived from extrusive igneous rocks.

In the case of the transported clays, which are universally associated with coal, the processes of normal weathering, aided by abundant carbon dioxide, are thought to be the cause of alteration, divitrification, and kaolinization which together gave rise to the formation of the clays. No such explanation, however, is considered adequate to reconcile the existing field relations found in certain of the residual clays which are derived from rhyolitic materials in the sediments. This problem is reserved for future discussion.

Structurally, the clays are found to reflect the diastrophism (faulting and folding) to which the enclosing sediments have been subjected. On the basis of a number of geological criteria, all of the deposits and sediments are in age definitely assigned to the Martinez formation of the Eocene portion of Tertiary time.